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RESEARCH ARTICLE

Comparison of tree diameter distributions in managed and unmanaged Kazdağı fir forests

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Abstract

Forest structural complexity affects tree growth, species diversity, understory seedling density, wildlife habitat and fire behaviour. Thus, defining the structural complexity of forest ecosystems would play a crucial role in their management. The vertical structure in stands of shade-tolerant tree species can be described by using the distribution of tree diameters. In this study, the main objective was to determine and compare the diameter distribution patterns of managed and unmanaged Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) forests in northern Turkey. Hierarchical clustering analysis was used to define the diameter distribution patterns. Three main diameter distribution patterns were examined in both managed and unmanaged forests. Two of the patterns in the managed forest did not possess the expected diameter structure of selection silviculture (i.e. reverse J-shape). The observed patterns in the unmanaged forest were mostly representative of the diameter structure of old-growth forests. Given the initial findings, it is likely that the small-scale disturbances created by selection methods may not be adequate to establish and recruit sufficient number of trees into small- diameter sizes in Kazdağı fir forests. The assessment of patterns of tree diameter distribution in these forests would create a basis for future research, aiming to enhance the structural complexity.

Keywords

Abies, biodiversity, diameter distribution, silviculture, stand structure

Introduction

The structure of forests plays a crucial role in the management of forest ecosystems. The complexity of the forest structure may enhance biodiversity (Gardner et al., 2009) and

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improve ecosystem services (Rutten et al., 2015). Forest structure consists of vertical and horizontal components and it is usually defined as species composition, size and distribution of trees, shrubs and ground cover vegetation (Podlaski et al., 2019). While vertical stand structure often refers to layering of tree crowns, horizontal structure mostly represents diameter size distribution and spatial patterns of tree species (Davis, Johnson, 1987). Stand structure of even-aged forests is mainly comprised of one distinct age and size class, while tree diameters are closer to the mean stand diameter. On the other hand, uneven-aged stand structure contains three or more age classes. In comparison to even-aged forests, uneven-aged forests exhibit higher structural complexity (Puettmann et al., 2009).

Structural complexity of stands affects density and growth of understory seedlings and saplings. Therefore, defining the structural complexity of forest ecosystems is essential for better management of forests. Previous studies have commonly used tree diameter distributions to define forest structural complexity (Uuttera, Maltamo, 1995). Vertical stand structure is mostly represented with distribution of tree heights. However, it can also be defined through the distribution of tree diameters in stands of shade-tolerant tree species due to the strong correlation between tree heights and diameters of these tree species (von Oheimb et al., 2005). Different vertical stand structures can be formed in forests of shade-tolerant tree species. Thus, the understanding of the linkage between diameter distribution patterns and future stand structure is essential for the successful and sustainable management of these forest types (Podlaski et al., 2019).

Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) is an ecologically important tree species in Turkey. The total acreage covered by the Kazdağı fir is about 670.000 ha that is approximately 3% of the total forested area of the country (General Directorate of Forestry, 2014). This tree species can grow up to 1 m in diameter and 30 m in height (Anşin, Özkan, 2006). The Kazdağı fir can form pure stands above 800 m a.s.l., while its mixed stands are mostly found at elevations between 1200 and 2000 m a.s.l. The species prefers north-facing slopes and deep clay soils. The Kazdağı fir is an endemic tree for Turkey and forests of this species exhibit rich species diversity within the northern part of the country (Odabaşı et al., 2004). In addition to its high quality timber, the Kazdağı fir forests also provide diverse ecosystem services, including wildlife habitat, water quality and recreation. The Kazdağı fir is considered highly tolerant to shady conditions, thus, the species can survive and grow under canopy for a prolonged period of time (Saraçoğlu, 1988). Both managed and unmanaged forests of this tree species are present in northern Turkey. Limited research has been done on the vertical stand structures in the managed and unmanaged Kazdağı fir forests (Sakıcı, Gülsunar, 2012).

Due to the influence of forest structure on tree growth, species diversity and wildlife habitats (Waltz et al., 2003; Kara, Lhotka, 2020a), forests managers are often interested in determining the structural complexity of their stands. Stand stocking and tree density of a forest is commonly manipulated through using diameter size distribution. Diameter distribution of forests vary depending on tree species, management type, stand dynamics and disturbance regimes (Loewenstein et al., 2000; Kara, Lhotka, 2020b). Although previous research has indicated that unmanaged Kazdağı fir-dominated forests can exhibit higher degree of structural complexity (Kara, Lhotka, 2020b), to my knowledge,

there has been no attempts to quantify and compare the diameter distributions patterns in managed and unmanaged Kazdağı fir forests. Therefore, the main objective of this study was to determine the tree diameter complexity of managed and unmanaged forests of this species in northern Turkey. It was hypothesised that there would be various diameter distributions patterns in both unmanaged and managed Kazdağı fir forests. The assessment of the patterns of tree diameter distributions in Kazdağı fir forests would create a basis for developing appropriate management practices that aims to enhance and maintain the structural complexity in the region.

Materials and Methods

Study area

This study was conducted in the Kastamonu City, northern Turkey (Fig. 1). Unmanaged (1100 ha) and managed (9000 ha) forests of Kazdağı fir were studied in the Ilgaz Mountain region. The study area is located within the natural distribution range of the Kazdağı fir (Fig. 1). The study area exhibits the typical characteristics of a continental climate with colder winters and rainy summers. The mean monthly temperature ranges from -4.7 °C in January to 14.6 °C in August, with the average annual temperature of 5.2 °C. The average total annual precipitation is approximately 1050 mm, with the maximum monthly precipitation occurring in May and a minimum monthly precipitation – in July. The growing season lasts approximately 137 days: from late April to late August. Brown calcareous is the dominant soil group, while soil depth is mostly moderately deep (50-90 cm). The topography is mainly defined by slopes ranging from 12% to 60% across the study area. The altitude of the study area ranges from 1200 to 2070 m a.s.l.

Scots pine (*Pinus sylvetsris* L.), black pine (*Pinus nigra* Arnold.), oriental beech (*Fagus orientalis* L.) and oaks (*Quercus* spp.) are other main tree species in the region. Understory vegetation is mostly comprised of the common juniper (*Juniperus communis* var. *saxatalis* Pall.), oaks, common hazel (*Coryllus avellana* L.), Cornelian cherry (*Cornus mas* L.) and blackberry (*Rubus fruticocus* L.). Although the Kazdağı fir could also form mixed stands within the region, pure (i.e., single species) Kazdağı fir stands were selected for the study.

Any silvicultural treatment was prohibited within the unmanaged forest since the early 1970s, after it was defined as a natural park. Thus, mainly natural stand dynamics prevail in the unmanaged forest. However, several recreational activities, including hiking and camping, are allowed within the park. Although no tree core was taken within the study plots, the management plan of the unmanaged forest indicated that most of the trees were at ages of 80-120. The managed forest, which is in close proximity to the unmanaged forest, has been primarily managed for wood production using single-tree selection method under the volume control-guiding diameter limit (VGDL) regulation (Guldin, Baker, 1998). A cutting cycle of ten-year and a target diameter of 52 cm are mainly employed when using the selection system in the managed forest. Based on the management plan of the managed forest, trees were mostly at ages

Figure 1. Natural distribution range of the Kazdağı fir and location of the study area.

of 40-80. Relatively denser understory vegetation was available in the managed forest as compared to the unmanaged forest.

Data collection and analysis

In both forests (i.e., unmanaged and managed), 30 400-m^2 (20 x 20 m) square measurement plots at an elevation of 1800 m a.s.l. were randomly visited in the fall of 2018. Study plots were exhibiting a growing-up developmental stage, in which young generation in the lower and mid story prevailed (Podlaski et al., 2019). Tree diameters at breast height (DBH) (cm) of all trees larger than five cm were measured to the nearest 0.1 cm in each measurement plot using a calliper. In total, 935 trees were measured in the unmanaged forest, while the total number of trees measured in the managed forest was 658.Using the DBH measurements, stand basal area (m^2 ha^{-1}), mean tree diameter (cm) and the number of trees per ha were determined for each study plot.

To identify the diameter distribution patterns, a hierarchical cluster analysis (HCA) was used. HCA usually represents a dendrogram that exhibits the homogeneous groups of

samples. The grouping is achieved using several metrics of samples distance. The concept of distance between the samples is fundamental in clustering. Euclidean distance measure, which is only suitable for continuous data, is usually preferred in clustering (Granato et al., 2018). Thus, clustering was performed using the Euclidean distance measure in this study. Each sample was considered as a cluster and the HCA aimed to group the clusters with similar features (Zhang et al., 2017).

The numbers of trees within 10-cm intervals from 5 to 85 cm were utilised as clustering variables in the HCA, as outlined by Podlaski et al. (2019). The number of trees in each interval was initially calculated for each study plot. In total, eight intervals were defined for each sampling plot. The clustering analysis was first conducted using four different methods, including "average", "single", "complete" and "Ward" methods. Next, based on the methods' agglomerative coefficients, which are measures of the clustering structures, the strongest clustering structure was chosen (Table 1). It should be noted that the agglomerative coefficient suggests a stronger clustering when its value gets closer to one. In this study, the Ward's method as the strongest clustering was utilised (Murtagh, Legendre, 2011) (Table 1). Ward's method is a commonly used criterion applied in cluster analyses and it is mainly recommended for quantitative variables (Glen, 2018).

In the HCA, the main concern was to define the number of clusters in the data. The optimal number of clusters, which is essential in hierarchical cluster analysis, has been found using the Average Silhouette Width Method (Rousseeuw, 1987). After the optimal number of clusters were defined, the diameter distribution patterns of each forest type (managed and unmanaged forests) were depicted. The average number of trees by diameter classes was obtained for each diameter distribution pattern using the data from the measurement plots, which represented the pattern. The HCA with the Ward's method was conducted using the "hclust" function in R statistical language, while the "agnes" and "pamk" functions were utilised to estimate the agglomerative coefficients of the methods and the optimal number of clusters, respectively (R Core Team, 2014).

Results

The average stand basal area of the unmanaged forest was significantly greater compared to the managed forest (95.5 and 35.5 m^2 ha^{-1}, respectively; Table 2). Moreover, the mean diameter was larger in the unmanaged forest than in the managed forest, while the number of trees per hectare was similar in both forest types (Table 2).

In the managed Kazdağı fir forest, the optimal number of clusters was three, meaning that three main diameter distribution patterns were present following the clustering analysis (Fig. 2). The patterns were designated as MF1, MF2 and MF3. In the dendrogram (Fig. 2), each leaf corresponds to one study plot and plots that are similar to each other have been combined into branches. The height on the y-axis represents the similarity or dissimilarity between two plots. A higher height of the fusion refers to less similarity between the plots. Each rectangle with different border colour (i.e., red, green and blue) represents a different diameter distribution pattern (i.e., MF1, MF2 and MF3, respectively). The numbers assigned to branches of the clusters represent the id number

of the measurement plots. MF1, MF2 and MF3 were represented by four, eleven and fifteen measurement plots, respectively (Fig. 2).

Similarly, to the managed forest, the optimal number of clusters for the unmanaged Kazdağı fir forest was also three. In other words, there were also three main diameter distribution patterns in the unmanaged Kazdağı fir forest (Fig. 3). The patterns in the unmanaged forest were designated as UMF1, UMF2 and UMF3. The first diameter distribution pattern (UMF1) was represented by 14 measurement plots, while there were four and 12 representing plots in UMF2 and UMF3, respectively (Fig. 3).

Figure 4 shows the diameter distributions of each forest type (managed and unmanaged forests). As stated above, the average number of trees by diameter classes was obtained for each diameter distribution pattern using the data from the measurement plots, which represented the pattern. For example, for MF1 pattern, the average number of trees per hectare from the representing plots (i.e., plots 1, 4, 3 and 2) was used. The same procedure was repeated for each pattern.

In the managed Kazdağı fir forest, MF2 and MF3 did not include any trees within diameter classes 60 (55-65 cm), 70 (65-75 cm) and 80 (75-85 cm), while the largest trees of MF1 were in diameter class 60. MF1 and MF3 lacked or had fewer trees in the middle diameter class (30 cm), while they had greater number of trees per hectare in the larger sizes (i.e., diameter classes 40 and 50 cm). MF2 exhibited a reverse J-shape pattern, referred also as negative exponential distribution. In this pattern, the number of trees per hectare decreased with increasing diameter classes.

As for the diameter distributions patterns of the unmanaged Kazdağı fir forest, UMF1 did not include any trees within diameter classes 70 (65-75 cm) and 80 (75-85 cm), while the largest trees of UMF2 and UMF3 were in diameter classes 70 and 80 cm, respectively (Fig. 4). UMF3 exhibited a bell-shaped diameter distribution pattern. Although UMF1 and UMF2 patterns represented close to normal distribution, their numbers of trees per

Table 1. The agglomerative coefficient values of clustering methods.

Methods	Agglomerative coefficient
Average	0.644
Single	0.528
Complete	0.760
Ward	0.814

Table 2. Descriptive statistics for stand basal area, trees per hectare, mean diameter in unmanaged and managed Kazdağı fir. SD refers to the standard deviation of the variables.

	Unmanaged forest				Managed forest			
Variables	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Stand basal area (m^2 ha^{-1})	60.5	120.5	95.5	14.7	22.4	65.5	35.5	10.4
Trees per ha	500	1200	780	151	300	1025	611	178
Mean diameter (cm)	34.5	50.2	40.0	3.7	19.5	40.5	28.5	8.1

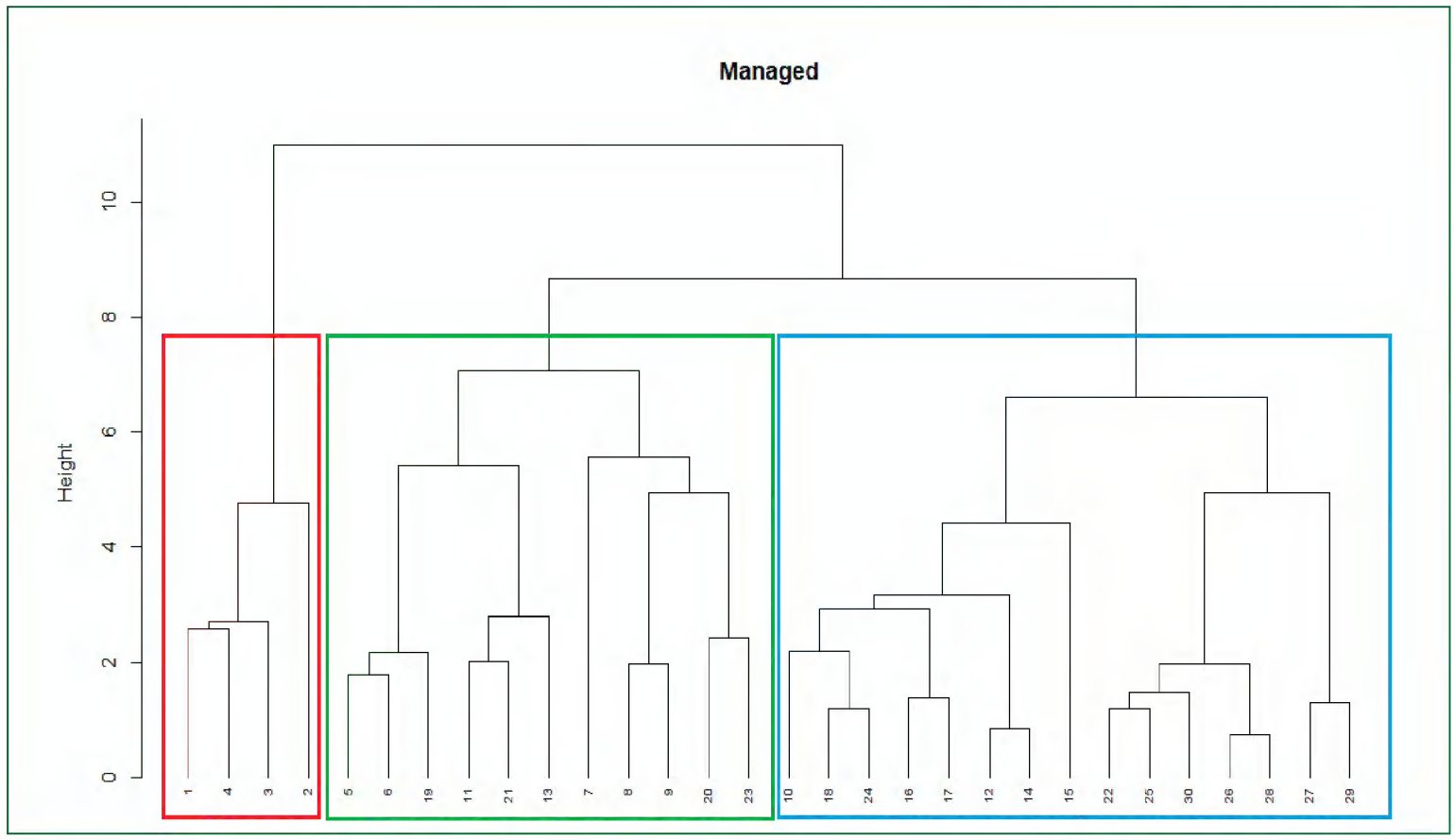

Figure 2. Clustering analysis of the measurement plots within the managed Kazdağı fir forest. Red, green and blue rectangles represent MF1, MF2 and MF3 patterns, respectively. The numbers assigned to the branches of the clusters represent the id of the measurement plots.

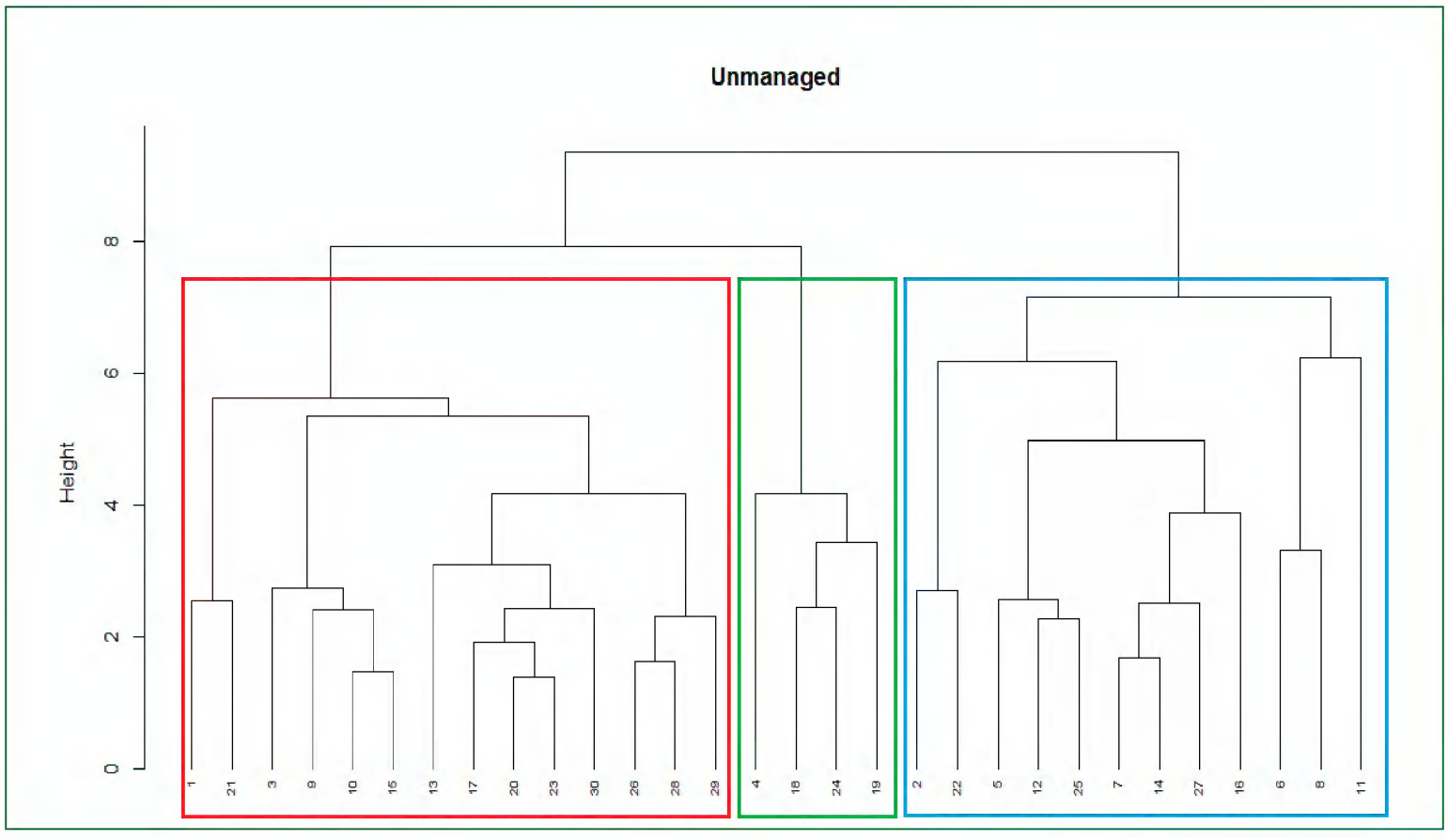

Figure 3. Clustering analysis of the measurement plots within the unmanaged Kazdağı fir forest. Red, green and blue rectangles represent UMF1, UMF2 and UMF3 patterns, respectively. The numbers assigned to the branches of the clusters represent the id of the measurement plots.

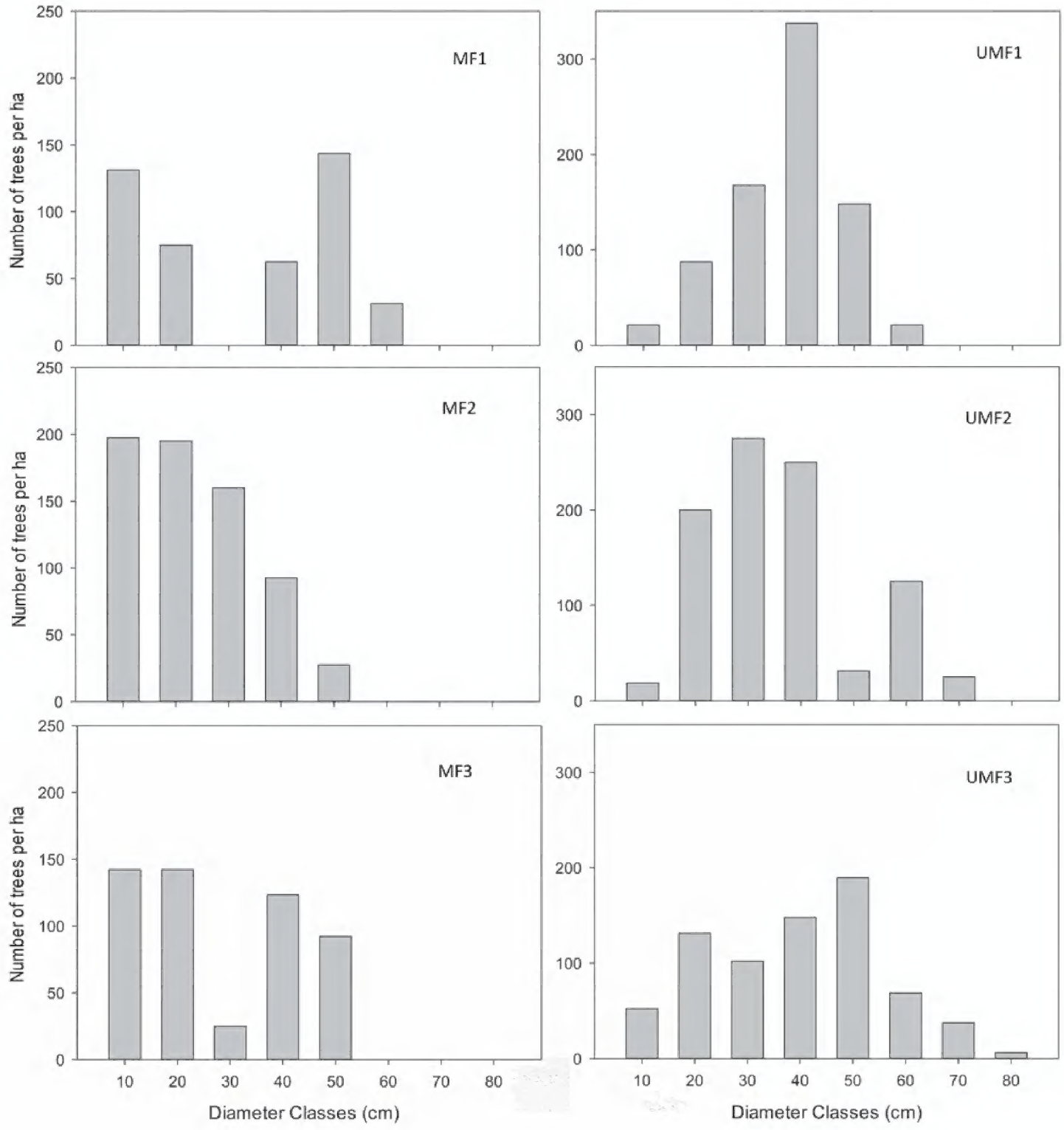

Figure 4. The diameter distributions of the managed and unmanaged Kazdağı fir forests.

diameter classes differed. Although UMF1 did not include any trees from the larger sizes, there was an accumulation of trees in the middle size diameter class (40 cm). UMF2 had fewer trees in diameter class 50 (45-55 cm; Fig. 4).

Discussion

A higher stand basal area of the unmanaged Kazdağı fir forest compared to the managed forest is particularly the case in forests of shade-tolerant species. The unmanaged forest had a greater number of trees per hectare and a higher average tree diameter than the managed forest. This mainly resulted in higher basal area in the unmanaged forest. It can

also be associated with the age differences between the managed and unmanaged forests. In a similar study, Keren et al. (2017) monitored the stand basal area in old- growth and managed beech (*Fagus* spp.), fir (*Abies* spp.) and spruce (*Picea* spp.) forests and found higher stand basal areas in the old-growth forests compared to the managed forests.

The Kazdağı fir is a shade-tolerant tree species that is commonly managed using selection silviculture under high tree densities in northern Turkey (Odabaşı et al., 2004). Small-scale disturbances through the selection methods are used to emulate the natural disturbance regimes in these fir forests within the region. As a result, a reverse J-shaped diameter structure is commonly expected in these managed forests. Previous studies have also monitored this diameter distribution in other forests managed through selection silviculture in Turkey (Yilmaz, Akay, 2008; Sakıcı, Gülsunar, 2012). Therefore, a greater number of Kazdağı fir trees was usually expected in the smaller size classes of the managed Kazdağı fir forest when using selection methods in these forests (Kara, Topacoglu, 2018).

In the managed forest, the pattern MF2 exhibited a reverse J-shaped pattern (i.e., a decreasing number of trees per hectare with increasing diameter classes), while MF1 and MF3 showed tendency to bimodality. The reverse J-shaped pattern is typical for unevenly-aged forests (Nyland, 2016). Podlaski et al. (2019) examined the diameter distribution of managed fir-beech forests and found a reverse J-shape pattern. In another study, Sakıcı, Gülsunar (2012) examined the diameter distribution of mixed fir-pine forests in northern Turkey and obtained a reverse J-shape pattern as well. Loewenstein et al. (2000) also found a reverse J-shaped pattern, while studying the diameter structure of a managed uneven-aged oak forest in Missouri, U.S.A. Nevertheless, the presence of trees in most of the diameter classes in the managed Kazdağı fir forest was indicative for the vertical structural complexity. The single-tree selection method in the managed forests of shade-tolerant Kazdağı fir usually maintained a multi-storied structure. This indicates that silvicultural implications can result in increased diameter structural complexity in managed forests (Keren et al., 2017).

The first pattern of the managed forests (MF1) in this study exhibited a bimodal distribution. This could be attributed to the effects of silvicultural cuttings in the managed forest. Selection cuttings aim to release the suppressed trees in lower and middle stories. Individuals under canopy may not respond well to the cuttings if the intensity and timing of the cuttings are not appropriate, especially in old forests (Odabaşı et al., 2004). Thus, previous small-scale disturbances created by the selection cuttings possibly were not adequate for the individuals under canopy to develop and to homogenise the diameter distribution in the managed forest. Moreover, a shorter cutting cycle can be used as an alternative to prolong canopy openness, which can favour the establishment and recruitment (O'Hara, 2006). Similarly, Kuuluvainen et al. (1996) observed stand structural heterogeneity in spruce-dominated forests and found bimodal distribution in the managed forests. In another study, Thomas et al. (2008) modelled the diameter distributions in mixed natural hardwood and conifer plantations in Canada and observed bimodal as well as unimodal distributions. Group-tree selection method can also be utilised as an alternative to the single-tree selection method, in order to create larger canopy spaces for recruitment into small and middle size diameter classes.

In general, plots in the unmanaged forest exhibited a bell-shaped diameter distribution pattern representing uneven-aged stand structure. This pattern could also be observed in old-growth forests. Old-growth forests are defined as the forests that have developed for prolonged time without human-caused or natural catastrophic disturbances (Peterken, 1996). Due to the limited overstory disturbances, usually fewer trees are available in the small size classes. Accordingly, Taylor (2010) monitored the forest structure in an old-growth forest of *Pinus ponderosa* in the U.S.A, and found that the diameter distribution of the live trees exhibited a bell-shaped distribution with uneven-aged structure. In another study, Zhang et al. (2010) discovered a close-to-normal distribution in old-growth Korean pine and broad-leaf forests.

Usually, the differences between managed and unmanaged forests in diameter distribution patterns can be associated with the silvicultural treatments occurring in the managed forests (Rouvinen, Kuuluvainen, 2005). The lack of large trees in the managed forest was likely because large trees had been harvested during each entry of the selection system. Similarly, Siitonen et al. (2000) also examined a broader diameter distribution in unmanaged forests of Norway spruce (*Picea abies* L. Karst.) compared to managed forests. Moreover, Uotila et al. (2001) also reported similar findings from natural and managed Scots pine-Norway spruce forests.

Previous studies suggest that old-growth forests should retain more than ten live trees per hectare larger than 70 cm in diameter to emulate the structural complexity of old-growth forests (McGee et al., 1999; Youngblood et al., 2004). Given the literature studies, two diameter distribution patterns of the unmanaged Kazdağı fir forest (i.e., UMF2 and UMF3 patterns) had structures suggestive of old-growth characteristics with approximately 30 live trees per hectare larger than 70 cm in diameter (Fig. 4). This study presents the current diameter distribution patterns in the managed and unmanaged Kazdağı fir forests. Thus, these patterns are subject to changes through time. According Podlaski et al. (2019), diameter distribution patterns are dynamic, thus, they can be maintained or driven to a target structure using different management strategies.

Since there had not been any silvicultural disturbance within the unmanaged forest for the last 50 years, natural stand dynamics prevailed in the forest. Although the unmanaged Kazdağı fir forest mostly exhibited the diameter structure of old-growth forests, the lack of trees in large size classes in some stands may be a concern for the maintenance of the desired structure. The characteristics of forest structure can affect biological diversity (Kerr, 1999). Sustainability of old-growth structure plays an important role for biological diversity, because old-growth forests usually possess higher species diversity than managed forests (Keren, Diaci, 2018). In this study, the biological diversity was not quantified. However, the biological diversity of the managed and unmanaged forests was compared based on their management plans. Within the unmanaged forest, 390 plant species were reported, of which 44 species were endemic. Moreover, 90 bird species and 21 species of mammals were reported in the unmanaged forest. In the managed forest, 260 plant species were recorded. In addition, 42 bird species and 14 mammals were also recorded within the managed forest. Thus, the unmanaged forest seems to be richer in biodiversity than the managed forest. In other words, the species diversity is likely enhanced through the old-growth stand structure.

Conclusions

This study examined the diameter distribution patterns in the managed and unmanaged Kazdağı fir forests in northern Turkey, using the hierarchical cluster analysis. Three main diameter distribution patterns were found in both managed and unmanaged forests of the Kazdağı fir. Two patterns in the managed forest did not possess the expected diameter structure of the selection silviculture (i.e. reverse J-shaped pattern). In the unmanaged forest, the diameter distribution patterns mostly represented the diameter structure of old-growth forests. The study findings highlight the importance of the intensity of overstory disturbances to establish and recruit sufficient number of fir trees into the small diameter sizes. Future monitoring is needed in order to establish whether the current diameter distribution patterns in these forests are subject to changes through time. The assessment of the patterns of tree diameter distributions of these forests in northern Turkey would contribute future studies that intend to enhance and maintain the structural complexity and the linked species biodiversity.

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